LEHIGH UNIVERSITY
Department of Mechanics
Bethlehem, Pennsylvania

SUBJECT: Fourth Semi-Annual Progress Report

REPORT PERIOD: June 1, 1965 through December 1, 1966

GRANT: N.A.S.A. Nsg 410 - Theoretical and Experimental Investigations of Fatigue Crack Growth

PRINCIPAL INVESTIGATOR: Dr. Paul C. Paris

A. INTRODUCTION

As mentioned in earlier reports and letters, Dr. Paris was on leave from Lehigh University September 1, 1964 to September 1, 1965. During that period, Dr. F. P. Beer, Head of Mechanics, acted as Administrator of the grant, and Dr. Paris returned periodically to Lehigh to direct the work.

During the period of Dr. Paris's absence, the work progressed well, as evidenced by Dr. Hertzberg's receiving the Ph.D. degree and Mr. Linder receiving his M.S. degree both in the summer of 1965. However, upon Dr. Paris's return, no research assistant was available for continued work under the grant. Dr. Paris did continue his individual studies under the grant through June 1966 and Dr. Makoto Isida, Visiting Professor of Mechanics at Lehigh University, spent the period February through June 1966 working on the research under this grant. Moreover, an undergraduate research participant, Mr. Francis Weiskopf, spent part-time (about 8 hours/week) during the Spring of 1966 on grant work, was reappointed in August of 1966 and is continuing his work under this grant. (During the period June

through August 1966, Mr. Weiskopf continued his grant work under the support of an N.S.F. Summer Undergraduate Research Participation Grant).

Moreover, though Mr. Linder left the university upon receiving his M.S., Dr. Hertzberg was appointed Assistant Professor of Metallurgy and Material Science and Director of the Mechanical Behavior of Material Laboratory of the Materials Research Center of Lehigh in September of 1965 and has continued his own work under the grant of other funds. He has had a Ph.D. candidate, Mr. Weber, working on this continuation at his thesis work. Recently, Dr. Hertzberg received an N.S.F. Grant to support further the continuation of his part of the work at no cost to N.A.S.A.

Moreover, an earlier Ph.D. recipient under this grant, Dr. J. R. Rice, is now Assistant Professor at Brown University and is also continuing his work under the grant. Therefore, although the grant work may appear to be slow in terms of expenditure rate, the research it has spawned under other funds is continuing at a high pace.

Beginning with September 1966, a Graduate Research Assistant, Mr. Hiroshi Tada, has been appointed under the grant. Mr. Tada has an M.S. degree from University of Tokyo during which his research was on crack arrestors which makes him very well qualified to aid in continuation of the grant work.

In accordance with a letter dated August 8, 1966 under the

signature of Dr. Holloway of N.A.S.A., the grant period is extended to June 30, 1967 within the amount of funds previously obligated. As of September 31, 1966, about $11,000 remained unexpended of the total of $73,000 provided under this grant. These remaining funds will be used to support the stipends of Mr. Tada and Mr. Weiskopf and the costs of their research and Dr. Paris is donating his own efforts to the project as part of Lehigh's contribution to this grant.

B. RESULTS TO DATE

In addition to reports previously mentioned in progress reports and correspondence with N.A.S.A., the following publications have been forthcoming:

(1) Dr. Paris travelled to the International Conference on Fracture in Sendai, Japan, in September 1965 to present:

"The Application of Electron Fractography and Fracture Mechanics to Fatigue Crack Growth", by R. W. Hertzberg and Paul C. Paris, Proceedings of the International Conference on Fracture, Sendai, Japan, 1965.

The proceedings are eminently due to be formally published whereupon reprints will be forwarded to N.A.S.A. as directed under this grant.

(2) Dr. Hertzberg presented at the A.S.T.M. Annual Meetings Symposium on Fatigue Crack Growth in June of 1966 (of

which both Dr. Paris, Principal Investigator, and Mr. Hardrath of N.A.S.A., the Grant Monitor, were on the Organizing Committee) the paper:

"Fracture Surface Appearance", by R. W. Hertzberg, to be published in an A.S.T.M. Symposium Volume, STP 415, 1967. Reprints of this paper will be forwarded to N.A.S.A. as soon as they are received.

NOTE: Publications (1) and (2) cover Dr. Hertzberg's Ph.D. work and some follow-up work so that sufficient publication of that part of the grant work is now completely accomplished.

(3) Dr. Paris, during the period in which his sole research support was under this grant, worked on a paper related to the grant work and it has been published. It is:

"On Cracks in Rectilinearly Anisotropic Bodies", by G. Sih, P. Paris and G. R. Irwin, International Journal of Fracture Mechanics, Vol. 1, No. 3, 1966.

Since the paper is not directly grant work, reprints have not been sent to N.A.S.A. to date. Moreover, the reprints are in short supply so the five are transmitted herewith and one will be sent to the Grant Monitor, Mr. Hardrath.

(4) In the same symposium volume mentioned in Reference (2),

Dr. J. R. Rice (now of Brown University) is publishing some heretofore unreported results which he obtained in conjunction with this grant, as well as other results he has obtained in a follow on effort.

No reprints of his work will be supplied to N.A.S.A. under this grant, but the "spinoff" is thought at least worthy of mention herein.

Other grant work now completed is being written or rewritten in a form suitable for publication as a N.A.S.A. document (note or report) or for publication in a technical journal. These include:

(1) Three reports by Dr. Makoto Isida, written as his contribution to the grant work, entitled:

(a) "Stress Intensity Factors for a Finite Crack Approaching the Boundary Between Joined Half Planes of Dissimilar Stiffness".

(b) "Stress Intensity Factors for Central Cracks in Periodic Strips Joined by Uncracked Strips of a Different Stiffness".

(c) "Crack Tip Stress Intensity Factors for a Crack Approaching a Hole Centered on Its Plane".

These reports have previously been transmitted to and discussed with Mr. Hardrath, the Grant Monitor. It

has been decided to combine the three into one report for publication through N.A.S.A. (Mr. Tada is currently working on the new draft among other things).

(2) The work done as represented by Mr. Linder's Master's Thesis, "Extremely Slow Crack Growth Rates in Aluminum Alloy 7075-T6", is still in draft form awaiting editing and perhaps some rewriting prior to submission for publication. This will be accomplished and transmitted to N.A.S.A. as the press of other work permits.

C. WORK IN PROGRESS

Mr. Hiroshi Tada will be working with Dr. Paris on the general subject of crack arrestors, analyzed both by theoretical calculations of their effectiveness and assessment of this effectiveness through their effects on fatigue crack growth. Mr. Tada has previously done such analyses before coming to Lehigh, and will refine them here. The experimental work is planned to begin in January 1967 with the availability of already designed test specimens and time on the necessary testing machines.

Mr. Weiskopf, the undergraduate research participant, will continue working with Dr. Paris on some special fracture tests of 7075-T6 of a configuration of interest in the testing of the fatigue crack growth properties of materials (this effort represents a rather minor expenditure under the grant).

Dr. Paris himself is continuing, as time permits, to explore

analytical models of fatigue crack growth. The objective of these studies remains as previously reported to be development of an improved analysis of accumulative damage in fatigue. Results to date on the effort have been discouraging and yet hopeful that a fresh fruitful idea will be forthcoming.

D. COMMUNICATION WITH THE GRANT MONITOR

Dr. Paris travelled to N.A.S.A. Langley Research Center for visits with the Grant Monitor, Mr. Hardrath, on two occasions during the period of this report

(1) In October 1965

(2) In July 1966.

During the winter and spring of 1965-66, Dr. Paris and Mr. Hardrath met or talked by telephone on numerous occasions precipitated by their common A.S.T.M. Committee interests, especially in their organizational effort on the "Symposium on Fatigue Crack Growth" which took place in June 1966. On these occasions, it was quite natural to also discuss grant business fully so that has led to a high degree of communication under the grant.

Moreover, Mr. Hardrath and Dr. Paris both participated in a two-week workshop on Fracture Mechanics in Denver, Colorado, in August 1966, which has led to an additional high degree of communication.

In addition, the principal investigator has also on at least

three occasions during the period of this report, visited N.A.S.A. Lewis Research Center on discussions related to but not directly on the grant work.

E. FUNDING AND DURATION

The current balance of about $10,000 as of December 1 will be sufficient to carry on the grant activities through the current period of the grant (ending June 30, 1967). Funds will be exhausted at or about that time. (Since currently all phases of the work are relatively new, continuation beyond June 1967 has not been discussed with the Grant Monitor or the Office of Grants and Research Contracts, but will be explored at an early date).

Paul C. Paris
Principal Investigator and
Professor of Mechanics

Enclosure: 5 Reprints